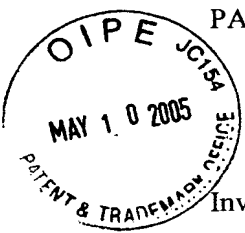


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PATENT

Docket No. A5GN2341US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventors : JOHN K. BEHEL and FRANK MURDEN  
U.S. Patent No : 6,861,903  
Issued : March 1, 2005  
Serial No. : 10/650,612  
Filed : August 27, 2003 Group Art Unit: 2817  
Title: SIGNAL COUPLING SYSTEMS WITH ENHANCED ISOLATION AND  
DYNAMIC RANGE

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Alexandria, VA 22313-1450

Certificate  
JUN 08 2005  
of Correction

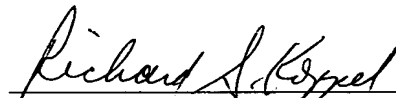
LETTER MAKING ERROR OF RECORD TRANSMITTAL

Sir:

Transmitted herewith is a Letter Making the Error of Record for the above issued patent and a copy of the patent specification as originally submitted to the PTO.

Respectfully submitted,

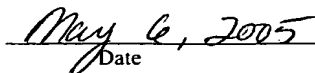
May 6, 2005

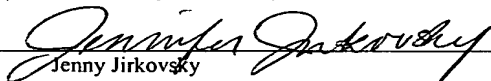
  
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CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as First Class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on:

  
Date

  
Jenny Jirkovsky



Docket No. A5GN2341US

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**LETTER MAKING ERROR OF RECORD**

Sir:

We have identified the following Patent and Trademark Office typographical error in the above patent, and request that this mistake be recorded in the file:

- Column 3, line 8, "60" should be "50" as listed on page 4, line 20 of the patent specification submitted to the PTO.

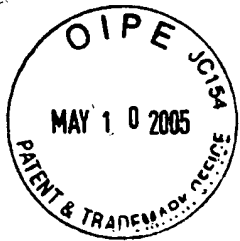
May 6, 2005

Respectfully submitted,

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APPLICATION

OF

JOHN KEVIN BEHEL

FRANK MURDEN

FOR

UNITED STATES LETTERS PATENT

ON

SIGNAL COUPLING SYSTEMS WITH ENHANCED ISOLATION  
AND DYNAMIC RANGE

Docket No. A5GN2341US

ASSIGNED TO

ANALOG DEVICES, INC.

5

## SIGNAL COUPLING SYSTEMS WITH ENHANCED ISOLATION AND DYNAMIC RANGE

10

### BACKGROUND OF THE INVENTION

#### Field of the invention

15 The present invention relates generally to gain-control structures stems and more particularly, to signal-coupling systems.

#### Description of the Related Art

20 Gain-control structures are particularly suited for use in feedback control loops that maintain substantially-constant signal amplitudes for a variety of electronic systems (e.g., wireless transceivers). In such use, a gain-control structure successfully reduces its gain in response to a large-amplitude source signal at its input. It has often been found, however, that the large signal amplitude disturbs junction biases in input transistors with consequent degradation of signal isolation and dynamic range.

25

### BRIEF SUMMARY OF THE INVENTION

30 The present invention is directed to signal coupling systems which enhance signal isolation and dynamic range. These advantages are realized with structures that increase bias voltages to guard against transistor saturation, decrease parasitic junction capacitances and turn off unneeded amplifier structures.

35 The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a signal coupling system embodiment of the present invention, and

FIGS. 2 and 3 are schematic diagrams of other signal coupling system embodiments.

5

## DETAILED DESCRIPTION OF THE INVENTION

FIGS. 1-3 illustrate signal coupling system embodiments of the present invention that enhance the system's signal isolation and dynamic range.

10

In particular, FIG. 1 illustrates a coupling system 20 for coupling input signals 21 from a plurality of system input ports 22 to a system output port 24. The system includes a plurality of signal amplifiers 26, a plurality of buffer amplifiers 28, a string 30 of impedance elements 31 and a current source 34.

15

The signal amplifiers 26 are each coupled to a respective one of the system input ports 22 and the buffer amplifiers 28 are each inserted between a respective one of the signal amplifiers and the system output port 24. Interstage junctions 36 are thus defined between the buffer amplifiers 28 and their respective signal amplifiers 26 and the impedance elements 31 are each coupled between a respective pair of the interstage junctions 36.

5

The coupling system 20 is especially suited for use in a gain-control system in which the signal amplifiers 26 are activated by respective control signals  $I_{c1}$ ,  $I_{c2}$ , ---  $I_{cn}$  and the input signals 21 are provided at taps 39 of a fixed attenuator 40 which receives a source signal at an upstream end 41 of the attenuator. As the source signal moves downstream through the attenuator 40, it is successively attenuated so that the amplitudes of the input signals 21 are least at the tap adjacent the downstream end 42 of the attenuator 40. With upstream and downstream directions thus established, it is noted that the current source 34 is coupled to the upstream end 44 of the string 30.

In a typical gain-control system application, the control signals  $I_{c1}$ ,  $I_{c2}$ , ---  $I_{cn}$  are provided (e.g., by a feedback loop) to maintain a

substantially-constant amplitude in the output signal 24 as the amplitude of the source signal varies from a minimum to a maximum amplitude. The source signal could be provided, for example, by an antenna or a radio-frequency amplifier stage in a signal receiver system. The output  
5 signal 24 would then be routed to other receiver elements, e.g., a signal mixer or an intermediate-frequency amplifier.

When the source signal is at minimum amplitude, a gain-control system would typically apply the control signal  $I_{c1}$  so that its corresponding signal amplifier and buffer amplifier would process their  
10 corresponding input signal 21 which is the strongest input signal. This comprises a high-gain state in which the gain from the source signal to the output signal 24 is greatest.

In contrast, the gain-control system would typically apply the control signal  $I_{cn}$  when the source signal is at a maximum amplitude so that  
15 this control signal's corresponding signal amplifier and buffer amplifier would then process their corresponding input signal 21 which is the weakest input signal. This comprises a low-gain state in which the gain from the source signal to the output signal 24 is least. As the amplitude of the source signal successively progresses from a minimum to a  
20 maximum amplitude, the gain-control system would successively apply the control signals  $I_{c1}$ ,  $I_{c2}$  ---  $I_{cn}$  to successively step the gain from the high-gain state to the low-gain state.

FIG. 1 illustrates a case in which a gain-control system has applied the control signal  $I_{cn}$  (in response to a strong source signal). The bias  
25 current 50 of the current source 34 then passes down the string 30 to the activated furthest-downstream signal amplifier 26. The resultant voltage drop across each of the impedance elements 31 generates successively-increasing bias voltages at the upstream signal amplifiers. As the amplitude of the source signal decreases and the gain is successively  
30 increased, the bias current 50 successively flows to signal amplifiers further upstream until it finally flows to the most-upstream signal amplifier.

The benefits of the bias current 50 and its generated bias voltages are more easily demonstrated with reference to the coupling system 60 of  
5 FIG. 2. This system also has an output port 24 but the signal amplifiers 26 and buffer amplifiers 28 of FIG. 1 are realized respectively as input

transistors 66 and cascode transistors 68 that are arranged to form cascode amplifier stages in which the cascode transistors 68 receive a first bias voltage  $V_{b1}$  on their bases. The string 30 of impedance elements 31 of FIG. 1 are realized as a string 70 of resistors 71 and the attenuator 40 of FIG. 1 is realized with a string of resistors 73 that receive a second bias signal  $V_{b2}$  at their downstream end.

The control signals  $I_{c1}$ ,  $I_{c2}$  ---  $I_{cn}$  of FIG. 1 are realized as control currents which are applied via current mirrors (CM) 76 that are coupled to draw signal currents from the emitters of the input transistors 66 (for clarity of illustration, only the current mirrors associated with the furthest-upstream and furthest-downstream input transistors are shown).

Similar to the coupling system 20 of FIG. 1, the coupling system 60 also has a current source 34 and the system is shown in a low-gain state in which this source's bias current 50 flows to the furthest-downstream input transistor 66. This would be the result when a gain-control system had placed the elements of FIG. 2 in the low-gain state because the amplitude of the source signal had risen to its maximum value.

Accordingly, the furthest-downstream input transistor 66 is currently activated and the bias current 50 generates voltages across each of the string resistors 71 so that the collector voltages of the input transistors 66 successively rise to a maximum collector voltage at the furthest-upstream input transistor. Therefore, the collector bias voltages of the input transistors successively increase as the amplitude of the source signal at their bases successively increases.

In an important feature of the invention, the successively-increased collector bias voltages insure that the upstream input transistors 66 do not saturate in the presence of large-amplitude source signals which would otherwise significantly increase current drain, reduce response time and possibly cause lock-up of an associated gain-control system.

In another important feature of the invention, the increased collector bias voltages successively decrease the parasitic capacitance associated with the base-collector junctions of the upstream input transistors 66. Accordingly, the invention raises the impedances at the bases of the upstream input transistors 66 which inhibits leakage signals that might otherwise transit these transistors and reach the output port

24 to thereby degrade the system's operation. In addition, the higher base-collector impedances prevent distortions in the source signal that would otherwise reach the furthest-downstream input transistor 66 and also degrade the system's operation.

5 As noted above, the cascode transistors 68 all receive a first bias voltage  $V_{b1}$  on their bases and the successively-rising collector voltages of the input transistors 66 thus inhibits turn on of the upstream cascode transistors. In simulations, it has been found that, generally, only immediately-adjacent cascode transistors will be turned on and their  
10 currents rapidly diminish in the upstream direction because of their successively decreasing base-emitter bias voltages.

In a high-gain state, a gain-control system would initiate the control signal  $I_{c1}$  which would activate the furthest-upstream input transistor 66. Immediately-adjacent cascode transistors will generally turn on but  
15 because their emitter currents generate successively rising voltages along the string 70 of resistors 71, it has again been found that only immediately-adjacent cascode transistors will be turned on and their currents rapidly diminish in the downstream direction.

FIG. 3 illustrates a differential coupling system 80 for coupling  
20 differential input signals from a plurality of differential system input ports to a differential system output port 84.

In the differential system 80, the signal amplifiers 26 and buffer amplifiers 28 of FIG. 1 are respectively realized as differential pairs 86 of first and second transistors and as first and second cascode transistors 88  
25 and 89 that are each arranged with a respective one of the first and second transistors of a differential pair to thus form cascode amplifier stages. The first and second cascode transistors 88 and 89 receive a first bias voltage  $V_{b1}$  on their bases. In different embodiments of the invention, the differential pairs 86 can be realized as multi-tanh doublets or triplets.

30 The string 30 of impedance elements 31 of FIG. 1 are realized as a first string 90 of first resistors 91 that are associated with the first cascode transistors 88 and a second string 92 of second resistors 93 that are associated with the second cascode transistors 89.

The control signals  $I_{c1}$ ,  $I_{c2}$  ---  $I_{cn}$  of FIG. 1 are realized as control  
35 currents which are applied via current mirrors (CM) 96 that are coupled to provide tail currents for the differential pairs 86 (to enhance clarity of



illustration, only the current mirrors associated with the furthest-upstream and furthest-downstream differential pairs are shown).

5 The attenuator 40 of FIG. 1 is realized as a ladder 100 formed with series and parallel resistors 101 and 102 to receive the differential source signal. Differential taps along the ladder 100 provide successively-attenuated versions of the differential source signal to the bases of the differential pairs 86 and a second bias signal  $V_{b2}$  is applied at the ladder's downstream end to provide a bias for these bases.

10 The coupling system 80 has first and second current sources 104 and 106 that respectively provide bias currents 110 and 112. In a high-gain state, the furthest-downstream differential pair 86 would be activated by the control signal  $I_{cn}$  and FIG. 3 illustrates that this would cause the bias currents 110 and 112 to flow through the resistor strings 90 and 92 to  
15 the furthest-downstream differential pair.

In response, the collector voltages of the other differential pair transistors successively rise to a maximum at the furthest-upstream differential pair. As gain is reduced, therefore, collector voltages of upstream differential pairs successively rise to protect them against  
20 saturation and to reduce their parasitic junction capacitances.

Signal coupling systems have been described which enhance signal isolation and dynamic range. These advantages are realized with structures that increase bias voltages in upstream signal amplifiers to guard against transistor saturation that would otherwise increase  
25 current drain, reduce response time and possibly cause lock-up of an associated gain-control system. Dynamic range is thus enhanced because these systems can operate over an extended range of source signals.

These structures also decrease parasitic junction capacitances which increases input impedances and thereby enhances signal isolation and reduces signal distortion. Buffer amplifiers are provided to enhance  
30 signal isolation which is further enhanced because the increasing upstream bias voltages turn off buffer amplifiers that are not currently required.

Simulations of the differential structures of FIG. 3 have  
35 demonstrated a substantially-linear gain response and a well-behaved

phase response which makes these structures especially suited for use in gain-control systems.

Although embodiments of the invention have been described with reference to bipolar junction transistors, other embodiments are formed  
5 by substituting various other transistor structures, e.g., complementary metal-oxide-semiconductor (MOS) transistors. This substitution is exemplified in FIG. 3 where a MOS transistor 120 is substituted for a cascode transistor 89 as indicated by substitution arrow 122.

Useful coupling system embodiments may be formed with strings of  
10 equal-valued impedance elements (31 in FIG. 1, 71 in FIG. 2 and 91 and 93 in FIG. 3) and also with strings of different-valued impedance elements. Although the impedance elements are resistors in FIGS. 2 and 3, they may be other devices, e.g., inductors, in other embodiments.

Current source 34 is coupled to an upstream end of the string 30 of  
15 impedance elements in FIG. 1 but, in general, the current source can be coupled in any manner that establishes bias signals along the string in response to activation of one of the signal amplifiers 26. The current amplitude and the magnitude of the impedance elements are preferably chosen so that the collector voltages of upstream signal amplifiers  
20 (e.g., 86 in FIG. 3) increase at least as much as the increase of the voltage of the source signal which appears at their bases.

The embodiments of the invention described herein are exemplary and numerous modifications, variations and rearrangements can be readily envisioned to achieve substantially equivalent results, all of which  
25 are intended to be embraced within the spirit and scope of the invention as defined in the appended claims.

We claim:

1. A coupling system for coupling input signals from a plurality of system input ports to a system output port, comprising:

a plurality of signal amplifiers each coupled to a respective one of said system input ports;

5 a plurality of buffer amplifiers that are each inserted between a respective one of said signal amplifiers and said system output port, interstage junctions thus defined between said buffer amplifiers and their respective signal amplifiers;

10 a string of impedance elements that are each coupled between a respective pair of said interstage junctions; and

a current source coupled to provide a bias current through said string in response to activation of one of said signal amplifiers to thereby establish bias signals along said string.

2. The system of claim 1, wherein said impedance elements are resistors.

3. The system of claim 2, wherein each of said buffer amplifiers and its respective signal amplifier are arranged as a cascode amplifier stage.

4. The system of claim 1, wherein each of said signal and buffer amplifiers is realized with bipolar junction transistors.

5. The system of claim 1, wherein each of said signal and buffer amplifiers is realized with metal-oxide-semiconductor transistors.

6. The system of claim 1, wherein said signal amplifiers are differential pairs of transistors.

7. The system of claim 6, wherein each of said buffer amplifiers comprises a pair of transistors that are each arranged as a cascode

amplifier stage with a respective one of the transistors of the respective differential pair.

8. The system of claim 7, wherein said buffer amplifiers and said signal amplifiers are formed with bipolar junction transistors.

9. The system of claim 7, wherein said buffer amplifiers and said signal amplifiers are formed with metal-oxide-semiconductor transistors.

10. The system of claim 7, further including an attenuator inserted to receive said input signals and provide successively-attenuated input signals to said system input ports.

11. The system of claim 10, wherein said attenuator is a resistive ladder.

12. A coupling system for coupling input signals to a system output port, comprising:

- an attenuator coupled to receive said input signals and provide successively-attenuated tap signals at a plurality of attenuator taps;
- 5 a plurality of signal amplifiers each coupled to a respective one of said taps;
- a plurality of buffer amplifiers that are each inserted between a respective one of said signal amplifiers and said system output port, interstage junctions thus defined between said buffer amplifiers and their respective signal amplifiers;
- 10 a string of impedance elements that are each coupled between a respective pair of said interstage junctions; and
- a current source coupled to provide a bias current through said string in response to activation of one of said signal amplifiers to thereby establish bias signals along said string.
- 15

13. The system of claim 12, wherein said attenuator is a resistive

ladder.

14. The system of claim 12, wherein said signal amplifiers are differential pairs of transistors.

15. The system of claim 14, wherein each of said buffer amplifiers comprises a pair of transistors that are each arranged as a cascode amplifier stage with a respective one of the transistors of the respective differential pair.

16. The system of claim 12, wherein each of said buffer amplifiers and its respective signal amplifier are arranged as a cascode amplifier stage.

17. The system of claim 12, wherein said impedance elements are resistors.

18. A coupling system for coupling differential input signals from a plurality of differential system input ports to a differential system output port, comprising:

- 5       a plurality of differential pairs of first and second transistors that are each coupled to a respective one of said differential system input ports;
- a plurality of first buffer amplifiers that are each inserted between a first transistor of a respective one of said differential pairs and a first side of said differential system output port, first interstage junctions thus defined between said first buffer
- 10       amplifiers and their respective first transistors;
- a first string of impedance elements that are each coupled between a respective pair of said first interstage junctions;
- a first current source coupled to provide a first bias current
- 15       through said first string in response to activation of one of said signal amplifiers to thereby establish first bias signals along said first string;
- a plurality of second buffer amplifiers that are each inserted

20           between a second transistor of a respective one of said  
            differential pairs and a second side of said differential  
            system output port, second interstage junctions thus defined  
            between said second buffer amplifiers and their respective  
            second transistors;

25           a second string of impedance elements that are each coupled  
            between a respective pair of said second interstage junctions;  
            and

30           a second current source coupled to provide a second bias current  
            through said second string in response to activation of one of  
            said signal amplifiers to thereby establish second bias  
            signals along said first string.

19. The system of claim 18, wherein said first and second buffer  
amplifiers each comprise a transistor arranged to form first and  
second cascode amplifier stages with their respective first and second  
transistors.

20. The system of claim 18, further including a resistive ladder  
inserted to receive said differential input signals and provide  
successively-attenuated differential input signals to said differential  
pairs.

SIGNAL COUPLING SYSTEMS  
WITH ENHANCED ISOLATION AND DYNAMIC RANGE

ABSTRACT OF THE DISCLOSURE

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Signal coupling systems are provided which enhance signal isolation and dynamic range with structures that increase bias voltages in upstream signal amplifiers to guard against transistor saturation that would otherwise increase current drain, reduce response time and possibly cause lock-up of an associated gain-control system. Dynamic range is thus enhanced because these systems can operate over an extended range of source signals. The increased bias voltages also decrease parasitic junction capacitances which increases input impedances and thereby enhances signal isolation and reduces signal distortion.

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